Texture in Materials
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Module - 04
Texture representation
Lecture - 14
Euler Angles and ODFs (Contd.)

Hello everyone, today we will continue with the lecture on Euler Angles, Euler Space and ODFs; that is Orientation Distribution Function. So, we are continue with the module four that is texture representation for the course texture in materials right.

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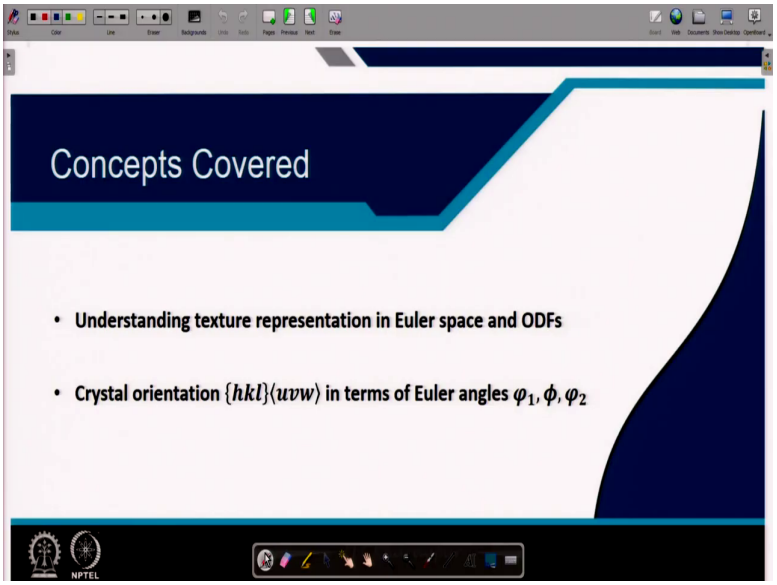

Therefore, in this lecture we will cover the concepts regarding understanding texture representation in Euler space and orientation distribution function. Relationship between crystal orientation; that is the orientation of the crystal with respect to important sample reference planes and direction h k l u v w right.

The rolling plane and the rolling direction in case of the rolled specimen. In terms of the Euler angle phi 1, phi, phi 2, which is used to observe the Euler space.

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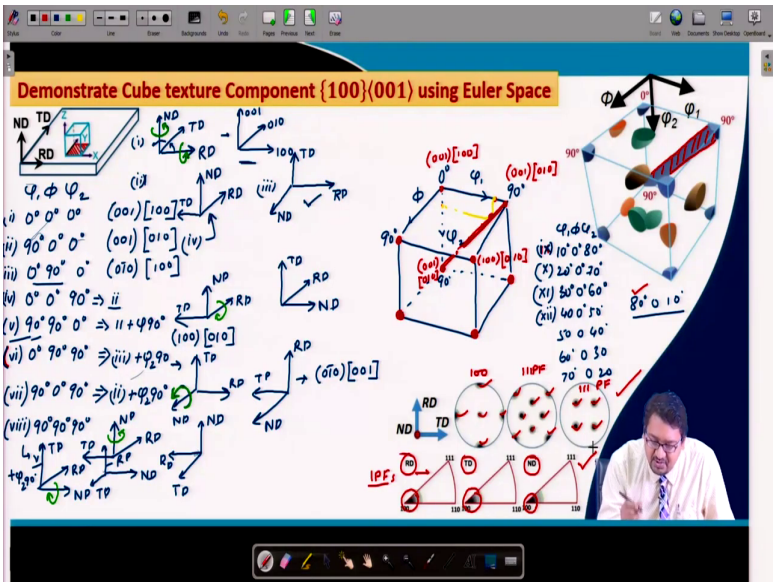

So, let us start with demonstrating the cube texture component that is the 100 001 components using the Euler angles that is in the Euler space. We have already observed the cube texture component as an example for the formation of a component in cubic crystals. So, these demonstrations that I will be doing here is related to the cubic crystal.

So, let us say that there is a sample which has been rolled and so the important sample reference directions are RD ND and TD right and the crystals which are oriented in the sample are mostly oriented same like this. So, x is 100 y is 0 0 1 0 and z is 0 0 1. So, the cube component as we have discussed earlier can be observed in this in this corner, in this corner, in this corner and in all the 8 corners of the Euler space that which are related to 0 0 0 degree of phi 1 phi phi 2 0 90 0 0 0 90 90 0 0 0 90 90 90 90 90.

And all the combinations of 0 and 90s in the phi 1 phi phi 2s right. Now, let us demonstrate it how we can obtain it from this sample crystal relationship. So, let us say that we draw our RD TD ND x's of the sample like this. And similarly, we can observe from this figure here that x is 1 0 0 that is the crystal coordinate system, 0 1 0 that is the another crystal coordinate system and 0 0 1 right. So, that RD is parallel to 1 0 0 TD is kept parallel to 0 1 0 and ND is kept parallel to 0 0 1.

So, if we want to find the Euler angles phi 1, phi phi 2 then the first condition is that we have to make ND parallel to some 1 0 0 and RD parallel to another 1 0 0, making it a cube texture component right. So, if initially I give a rotation of 0 degree along phi 1, that is a rotation of 0

degree along ND of the specimen axis and then we give then the RD remains at 1 0 0 the TD remains at 0 1 0 and ND will be 0 0 1 because we are rotating about ND, so ND is not moving.

And, then if we rotate again phi by 0 degree the ND and TD remains the same along with RD and then again if we rotate by 0 degree along phi 2. So, the specimen axis is not rotated at all with respect to this crystallographic axis right. So, what we are doing is, we are obtaining the first Euler angles for the cubic h k l u v w orientation of ND which is 0 0 1 right, ND is parallel to 0 0 1 and RD is parallel to 1 0 0 right.

Now, so therefore, if we are drawing say for example, we draw this Euler space again right, the same Euler space that has been drawn in this side I am trying to draw it again then what will happen, then this is the Euler space right

So, this is 0 degree this is 90 degree, this is a again 90 degree and considering the crystal symmetry for the the cubic crystal you can observe that there is four fold symmetry along 1 0 0 axis which makes the Euler angle fixed at 0 to 90 degrees for phi 1, phi and phi 2. And we will discuss this also later in detail. So, say this is phi 1, say this is phi and say this is phi 2 right and these are going like this right.

Now, we see that the first position 0 0 0 degree is this position right . Now, therefore, if we take this component and we can say that this component is related to 1 0 0, sorry this is a small mistake 0 0 1 and 1 0 0 right. Now, let us take another component and let us say that I am rotating this phi 1, phi phi 2 by say 90 degrees 0 degrees and 0 degrees and so we have to rotate phi 1 by 90 degrees. That means, that we have to rotate ND that is this 1 by 90 degrees using the right hand thumb rule right.

So, I have to rotate something like this. Let us use another pen and let me show you how the rotation is done. So, I am rotating it by the right hand thumb rule like this right. So, initially this was the case 1, and now the case 2 that I would like to show is rotating the ND by 90 degrees, what we can obtain is the RD is rotated and it goes towards TD and the TD is rotated by 90 and goes towards parallel to RD. So, now, the second case becomes ND is on the top, RD is now parallel to the initial TD, and the TD is here right.

So, this is the second case and in this case what happens that ND remains parallel to 0 0 1 and RD becomes parallel to 0 1 0 right. So, the position 90 0 0 can be shown here in the Euler

space at phi 1 equal to 90 phi equal to 0 and phi 2 equal to 0 and that becomes equal to this position and that becomes equal to 0 0 1 0 1 0 right. If we if we continue doing this for the 3rd, example what we can see 0 degree 90 degree, 90 degree can be done and the thus if we do that what happens that if we take the third condition that is this third condition we have to rotate by phi equal to 90 degrees; that means, the rotation has to be done along RD right. The rotation has to be done along RD using the right hand thumb rule and which is like this right. Let me take another color and let me show you that this has to be something like that right.

Now, if such a situation exists then the phi 1 phi phi 2 0 90 0 degree ok, let me let me take this and 0 degree can be shown by rotating RD by 90 degree, so that the TD comes vertical like this and the ND comes out like this right. Therefore, ND just comes out opposite of TD. Now, if ND is like this then the ND is 0 1 bar 0 right and the TD sorry the RD is 1 0 0. Therefore, the position of the pole of the cube component is at 0 90 0. Therefore, phi 1 is 0 phi equal to 90 and phi 2 is 0. So this is the position right. Another position we can find out like this similar way, if we go ahead and this situation where phi 2 equal to 90 is given following phi 1 equal to 0 and phi equal to 0 is similar to that of the second situation which where phi 1 is given 90 degree rotation.

So, that this is a situation where we are giving a rotation like this similar. Let me show you that four is similar to this one, where we have rotated using the right hand thumb rule ND by 90 degree. So, RD is here and TD is here. So that this is 0 0 90. So this is a position where this will form let me show, so this is the position of another cube component which is having a texture of in terms of miller indices. If you say, 0 0 1 0 1 0 right and like that if we look into, fifth one where we are rotating by 90 degree and then we are rotating again by 90 degree along phi and then by 0 degree. That means, we are taking the two and we are rotating by phi equal to 90 degrees right, which is given along RD.

So, if we are taking this section TD and ND and then we are taking RD and then, if we are rotating along RD right using the right hand thumb rule again right like this, then what happens is that ND rotates and it forms here, whereas TD which is here, now forms here right.

Whereas, ND sorry the RD remains at the same position. Therefore, the fifth position is ND is parallel to 1 0 0 whereas, RD is parallel to 0 1 0 right. So, we can write 90 90 0 that is phi 1 90 phi 90 and phi 2 equal to 0 can be kept here, and this is another component 1 0 0 0 1 0

right. Now, if we go ahead and do this for the sixth section that is 0 degree, 90 degree and 90 degree.

If we do this what will happen? We have to take the phi equal to 90 degree that is the third one, this one and then we have to rotate by phi two equal to 90 degrees right. And now how this will happen? Let us take this one, which is given here right. Now, we take this TD, this ND and this RD right, and we give a rotation by using the right hand thumb rule right the right hand thumb rule like this let me use the another color so as to you for understand, and then what will happen, that RD will go at the top and the TD will go here and ND will remain at the same position.

So, ND becomes 0 1 bar 0 and RD becomes 0 0 1 right and this is a position 0 90 0. So, 0 90 and then 0. Therefore, this is a position, which is shown by this. Like that if we go ahead and do the seventh one that is 90 degree at phi 1, 0 degree at phi and then again 90 degree at phi 2, then what will happen that we have to take the two and then rotate by phi 2 at 90 degrees.

So, if we take the two, one then this is like this and then this is the second one. So this is ND, this is RD and this is TD for the second one, 90 0 0. And then, we are rotating again by 90 degrees along ND right, because its a phi 2 equal to 90 degree rotation and thus what will happen that the RD will come here right and the TD will come here and the ND will come here right.

So, that in this way we have traced almost all the phi 1 phi phi 2s respect to the cube components in the Euler space and this was 90 0 90. Therefore, it is 90 and then it is 0 along phi and then again 90, so it is this position is here and like that we can device the eighth one which is 90 degree, 90 degree and 90 degree. So, in order to do so, we can take the fifth solved axis which is ND RD and TD and then rotate the fifth one by phi 2 equal to 90 degrees. So, what we are doing? , we are taking the ND here and rotating it like this using the right hand thumb rule, so that the ND remains the same right, the RD because we are rotating like that, so RD comes up. So, this is RD and the TD comes here. So, thereby we also obtain the position of the cube component at this.

So, there are cube components present in all the 8 corners. However, there are more cube components present and these cube components, which are present in this Euler space, are also shown in terms of the fiber, which is shown here right, this fiber. Now, how it can be shown? Now, that if we take the the ninth sorry I will change the color the ninth situation

where if we rotate by phi 1 phi phi 2 by 10 degree 0 degree and then I have to rotate phi 2 by 80 degrees so that phi 1 plus phi two becomes 90 and its your rotation along ND by 90 degrees divided among phi 1 and phi 2 right.

So, and then we can do this for 20 degrees at 70 degree, 20 degree phi 1 and phi 2 at 70 degree. Then the eleventh case, 30 degree and 60 degrees right. And the other cases right twelfth case like 40 degrees and 50 degrees right, and like that 50 degrees and 40 and 60 0 30 and 70 0 20 80 0 10 right. So, that let us take phi 1 equal to 80, phi equal to 0 and phi 2 equal to 10 degrees right in this Euler space. And, we can observe that if we look phi 1 equal to 80 it will be somewhere here right, and then if we take phi equal to 10 it will be sorry phi 2 equal to 10 it will be somewhere here. So, let us use some other color right.

So some one here as and then if we trace this point and then we see that this is related to this component right. Similarly, we can trace 70 20 somewhere here, 60 30 somewhere here and then we can relate everything, and then that it is forming of fiber here. Therefore, like that the cube component in an Euler space not only form components at the corner but also forms a fiber in the phi 1 phi 2 plane where phi is equal to 0. Now, this cube component that we have devised using the Euler space can be shown using the pole figures and here you can see that this is the 1 0 0 pole figure which shows the positions of the cube components in terms of 1 0 0 poles.

Here is the 1 1 1 pole figure and all this we have described previous in previous lectures, these are the 1 1 0 poles which shows the same texture, and this is the 1 1 1 pole figure which shows the positions of this cube component here in terms of 1 1 1 pole. Similarly, inverse pole figures can also be used to show this texture components right. Now, that in the inverse pole figure one can easily find out that the position of 1 0 0 is should be for the RD right. Similarly, for the ND the position is again 1 0 0 and thereby as 1 0 0 0 0 1 and 1 0 1 0 are perpendicular to each other therefore, TD also comes along 1 0 0. So, this is the way we can demonstrate the texture in terms of pole Euler space, in terms of pole figure, in terms of inverse pole figure. Now, it is even it is difficult to observe this situation in the Euler space.

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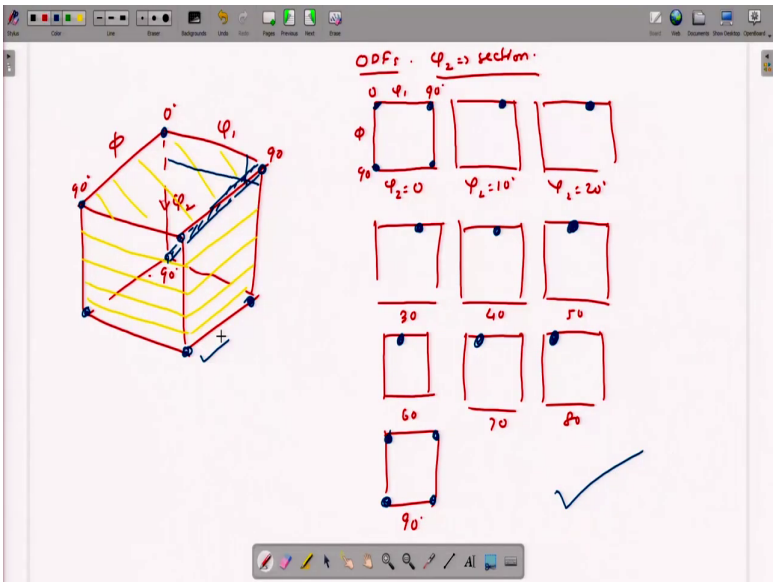

Therefore, what we do is instead of showing the Euler space which shows this positions of the cube orientations, and I am drawing it once again for your convenience. 0 degree, 90 degree, 90 degrees and 90 degrees here, and this is phi section, this is phi 1 section, this is phi 2 section and you can see that the positions of the cubes are cube components are this and this.

In addition, if we look we can see that here we also have fiber which actually shows the cube component right. However, instead of showing it in terms of Euler space like this, what we do? We show them in terms of ODFs which we show in terms of phi 2 sections most of the time, but that does not mean that we cannot show the ODFs in phi sections or phi 1 sections. It depends that when and what is required is shown for clarification and for easy analysis.

So, that if we divide this Euler space into phi 2 sections say, let us say that we take this particular plane and we draw it here and we show that ok this is phi 2 equal to 0 right and then this is phi 1 and this is phi and so this is 0 for phi 1 and 90 degree and this is 0 for phi and 90 degree here and like that the we can slice this Euler space at 5 degrees or 10 degree graduation right like this many. And like that, if we show the phi 2 equal to 10 degree section and phi 2 equal to 20 degree section and like that .

I am drawing it little faster, so it may not be so beautiful, but I am trying to show you something that will help you in understanding the representation of the texture, where phi 2 equal to 0 10 20 30 40 50 60 70 80 and 90 degrees, then the position of the cube components

at phi 2 equal to 0 degrees are the corner positions right. So, it will be shown somewhere here, somewhere here and somewhere here and similarly when at phi 2 equal to 90 degree section it is shown again in the corner, so it will be shown here and here right. Now, if we look into phi two equal to 10 degree section the position will be somewhere at phi 1 equal to 80 degrees right, as we have said. So, we will find the position here, at phi 2 equal to 20 degree the phi 1 position will be at 70 degrees and then at 30 degrees it will be at 60 degrees and at 40 degree it will be at 50 degrees, at 50 degrees it will be at 40 degrees and at 60 degrees it will be at 30 degrees and then 20 degrees and 10 degrees and at 0 degrees.

So, this is how the cube components look when we observe them in the orientation distribution function. So, that is all for the cube component. So in this way we can observe that how cube texture can be represented using the Euler space and the orientation distribution functions in phi 2 equal to 0 to 90 degree sections which can be graduated at 5 degrees or 10 degrees as suitable.

Thank you very much.